EASTERN PACIFIC CROWN-OF-THORNS STARFISH POPULATIONS IN THE LOWER GULF OF CALIFORNIA

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ABSTRACT.— Populations of *Acanthaster ellisii* (Gray) were investigated on three islands in the southern Gulf of California. Average density (0.0045/m^2 or 1/225 m^2) exceeded that given in several definitions of normal densities for *A. planci* populations in the Indo-Pacific. Small patches of *Porites* were the most frequent food item; other hermatypic scleractinians, gorgonians, and algae were also fed upon. Estimates of coral coverage and growth rates, and *Acanthaster* feeding rates, indicate that *Acanthaster* predation is a significant source of coral mortality but that corals are not being eliminated from the areas studied. Gonad analysis suggests an extended spawning season rather than a short synchronous one. Size-frequency data do not necessarily lead to the conclusion that populations of *Acanthaster* are expanding.

RESUMEN.— Se estudiaron las poblaciones de *Acanthaster ellisii* (Gray) en tres islas de la zona meridional del Golfo de California. La densidad de dichas poblaciones presentaba un promedio de 0.0045 por m^2, o sea de 1 por 225 m^2, que vienen a ser concentraciones más elevadas que las consideradas normales para. *A. planci* en el *Indo-Pacífico*. Pequeñas agrupaciones de *Porites* constituyen el alimento más frecuente de estos equinodermos, aunque también se observó que se alimentan de otras escleroactinias hermatípicas, gorgonias y algas. Las determinaciones sobre la cobertura de corales y los valores de crecimiento, así como los datos relacionados con la alimentación de *Acanthaster* indican que la predación de este equinodermo es uno de las causes principales en la mortalidad del coral, aún cuando los corales no aparecían exterminados en las zonas estudiadas. El análisis de las gónadas sugiere que la época de puesta no es corta y sincrónica, sino prolongada. Datos sobre la frecuencia de tallas no indican, al parecer, que las poblaciones de *Acanthaster* amplien su area de dominancia.

INTRODUCTION

The presence of conspicuous populations of the eastern Pacific Crown-of-Thorns starfish *Acanthaster ellisii* (Gray) on three islands just north of La Paz, Baja California, Mexico, was recently brought to our attention. In the central and western Pacific in areas of luxuriant reef development the closely related starfish *Acanthaster planci* (Linnaeus) is reportedly undergoing population explosions (Barnes 1966; Weber 1969; Chesher 1969, 1970). Reputed consequences of these "infestations" range from economic disaster for small isles and atolls of Oceania, destruction of fisheries upon which the inhabitants of Oceania depend for almost all their protein, severe land erosion by storm waves, to the extinction of madreporarian corals in the Pacific (Chesher 1969). More recently the assertions that *Acanthaster* aggregations represent a massive environmental upheaval, which seems to have no recorded precedent, have been challenged (Newman 1970; Weber and Woodhead 1970; Dana 1970). However, since no complex coral reef structures comparable to those of the Indo-Pacific are to be found in the Gulf of California, the presence of populations of *A. ellisii* apparently exceeding densities given as normal by Chesher (1969) for *A. planci* posed intriguing questions as to the ecological relationships between eastern Pacific corals, *A. ellisii*, and reef formation. Goreau (1964) has even suggested that under certain conditions *Acanthaster* might be an important factor limiting the growth and development of coral reefs. This prompted a short but intensive survey of

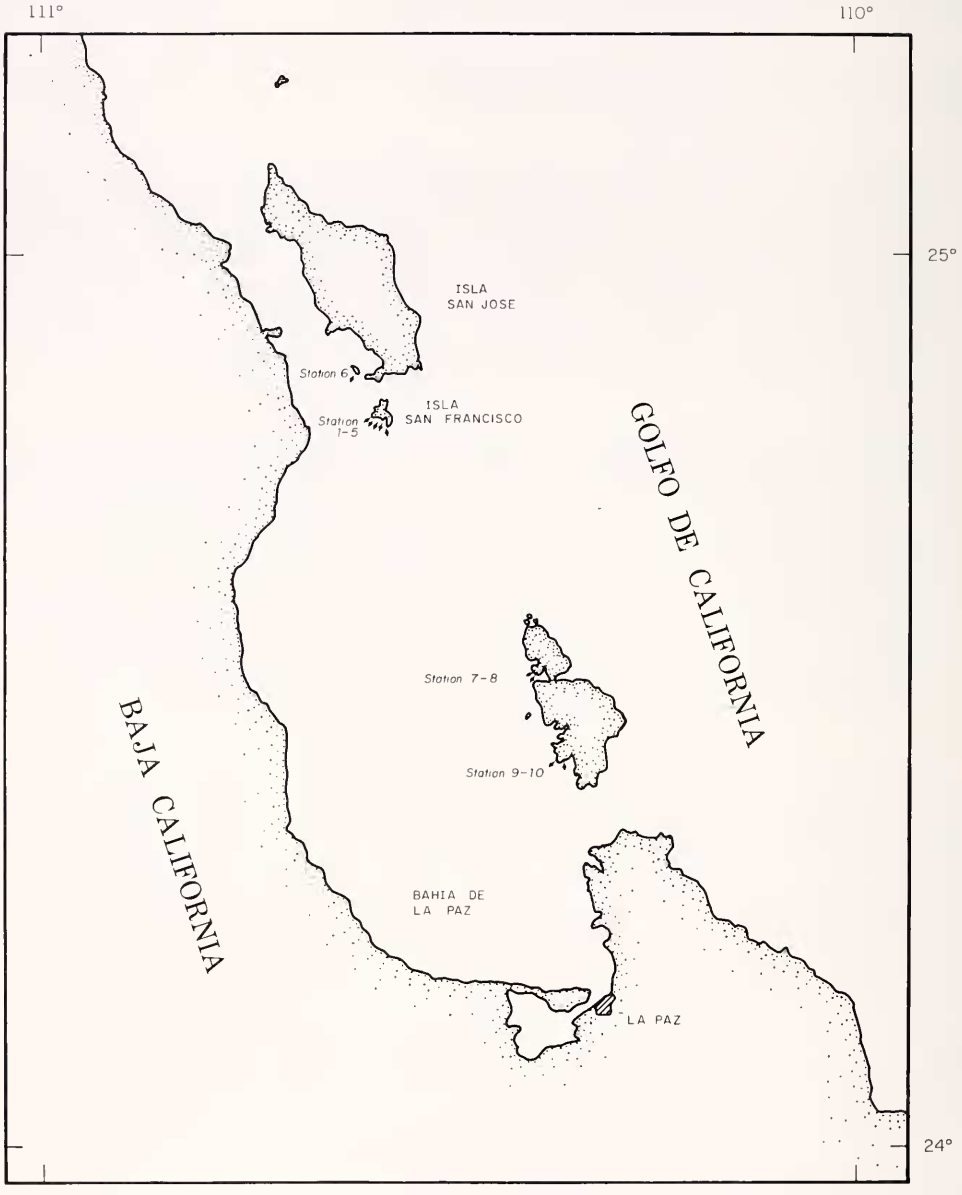

Figure 1. Map of study area in lower Gulf of California, Mexico showing station locations.

Isla San Francisco (24°55′N, 110°35′W) on 23 and 25 April, Isla San Jose (24°55′N, 110°35′W) on 24 April, and Isla del Espiritu Santo (24°35′N, 110°25′W) on 26, 27, and 28 April, 1970, to investigate various aspects of the ecology of those populations (Figure 1).

METHODS

Area, depth, and per cent coral coverage of all surveyed areas were estimated. Usually

in making surveys two divers were towed at slow speeds (1 to 2 knots), one on each side of a 12′ skiff. In early stages of the survey all *A. ellisii* located were investigated for active feeding; later only occasional individuals were checked. Frequently, when visibility and the width of suitable substrate prohibited a thorough survey by towing, free or SCUBA diving was employed to more completely cover the area. At several stations both day and night observations were made. Only diving was utilized for night surveys, during which special emphasis was placed on locating juvenile *A. ellisii* (none were found). Specimens were collected from selected areas and individuals were kept in a large opaque aquarium on board ship. A variety of living corals were presented to these specimens. All the *Acanthaster* collected were measured (disk diameter) and gonad samples taken.

RESULTS

Isla San Francisco. — The area adjoining nearly the entire western half of the island was surveyed. Detailed observations were, however, limited to the southwestern sector.

Station 1 was the submerged portion of a spit composed of small boulders (<0.5m in diameter) at the southern end of a small sandy embayment. The area investigated measured some 120×10m, with depths ranging from 0.5 to 2m. All observations were made while snorkeling. Coral coverage was 2 to 3%, consisting of small patches of *Porites* (3-6 cm in diameter) and scattered individual heads of *Pocillopora.* Seven *A. ellisii,* all in the open, were located; most were feeding on small *Porites* patches during the day. There was evidence of occasional feeding on *Pocillopora,* but none of these coral heads were completely eaten. (Density of *A. ellisii:* $0.006/m^2$ or $1/171m^2$.)

Station 2 was located along a rocky shoreline across the sandy embayment from Station 1 and included the point at the northwestern end of the bay. The substrate consisted of large boulders (>1m in diameter) that had tumbled down onto a flat sandy bottom. These boulders were almost completely covered with algae. The area surveyed stretched for about 315m along the shore and varied in width from 8m on the inner end to 15m at the northwest point. Depth of the water to sand bottom gradually increased from 5 to 15m at the point. Day observations were made towing, free diving, and with SCUBA. Coral coverage was estimated to be less than 1%, except at the point where it was between 2 and 3%. Small encrusting patches of *Porites* and small heads of *Pocillopora* were present. Several larger heads of *Pocillopora* and patches of *Porites* (>30 cm in diameter) were found in shallow water at the point. A total of 27 *A. ellisii* (including 7 taken by Faulkner on 18 April) were scattered throughout the area. Nearly all were in water between 1 and 5m deep and were feeding on patches of *Porites.* A single individual which was not feeding was found in 12m of water at the northwest point. (Density of *A. ellisii:* $0.009/m^2$ or $1/117m^2$.)

Station 3 began on the north side of the point where Station 2 terminated and continued for some 200m into an adjacent cove. The substrate was similar to that of Station 2 except the boulders were smaller and less algal covered. The rocky area was 5 to 8m wide, ending on a smooth sand bottom in 3 to 4m of water. Coral coverage was estimated to be less than 1%. Four *Acanthaster* were seen but were not checked for feeding. (Density of *A. ellisii:* $0.003/m^2$ or $1/400m^2$.)

Station 4 was located on the north side of a small cove opposite Station 3. The substrate along the inner 75m of the cove was a grey, vesicular basalt dipping seaward gently for about 18m to a depth of 3 to 4m, and then more sharply to a smooth sand bottom at a depth of 9m. This area was surveyed by towing and free diving during the day. The bottom over the remaining 310m length of the area consisted of large boulders and was surveyed by day towing and a SCUBA dive at night. The entire station was densely covered

with algae. Coral cover was between 1 and 2% and consisted of small patches of *Porites* and occasional small heads of *Pocillopora*. A total of 24 *Acanthaster* (including 12 collected by Faulkner on 19 April) were found at this station. Most individuals observed during the day were feeding in the open on small patches of *Porites*. Identical behavior was observed during the night dive with the additional observations of one completely cleaned colony of *Pocillopora* and a single *Acanthaster* feeding on a gorgonian (*Pacifigorgia* sp.) in a crevice. (Density of *A. ellisii:* $0.006/m^2$ or $1/160m^2$.)

Station 5, located along the southern side of the cove adjacent to Station 4, comprised an area of 300 x 10m. The bottom was an algal-covered sloping rock outcrop with a few boulders scattered at its seaward extremity. Sand replaced the rocky substrate in about 3m of water. Observations were made by towing and free diving in daylight. Coral coverage was 8 to 10%, consisting principally of encrusting to submassive patches of *Porites*, a few heads of *Pocillopora*, and an occasional patch of *Pavona*. (Density of *A. ellisii:* $0.002/m^2$ or $1/600m^2$.)

Isla San Jose. — A single station (Station 6) was made at this island — around a linear rock outcrop well out into the mouth of the large bay on the southwestern extremity of the island. The substrate consisted of large algal covered boulders, and water depth to sand bottom ranged from 6m at the northern end of the outcrop to 14m at the southern end. The area surveyed was about 375m long and 10 to 12m wide. Corals present were *Porites, Pocillopora,* and *Tubastrea,* and cover for most of the area was about 1%, increasing slightly at the southern tip where a strong current prevailed. Observations were made towing and with SCUBA. During the day 5 *Acanthaster* were found scattered along the western side of the outcrop, all in less than 4m of water. Three were in the open, fully exposed but not feeding, another was feeding on a gorgonian (*Pacifigorgia* sp.), and one had its stomach everted over a clump of *Padina* sp. (a lightly calcareous brown alga). All of these specimens were collected and no additional individuals were located that night. (Density of *A. ellisii:* $0.001/m^2$ or $1/750m^2$.)

Isla del Espiritu Santo. — Two stations were occupied in the northwestern sector of the mouth of an embayment on the western side of the isthmus. The first, Station 7, was around a small rock outcrop a short distance out into the bay. The surveyed area was approximately $500m^2$. All observations were made snorkeling during the day. Algal cover was much sparser than at previous stations and coral coverage was between 4 and 5%. Small patches of *Porites* were present, a single clump of *Psammocora (Stephanaria)* was noted, and a number of colonies of *Pocillopora* (up to 0.75m in diameter) were scattered about. Eight *Acanthaster* were observed in 1 to 3m of water. (Faulkner also collected one individual from this locality on 15 April.) Of the 8, 7 were feeding on tiny patches of *Porites,* and one was under a large head of *Pocillopora* — a small portion of which had been eaten. (Density of *A. ellisii:* $0.016/m^2$ or $1/63m^2$.)

A small point opposite Station 7 was selected for Station 8. An estimated 1100m of rock outcrops and boulders were investigated by free diving. Algal and coral coverage, as well as the kinds of corals, were similar to Station 7. Of the 8 *Acanthaster* seen during the day, 6 were feeding on *Porites* and one on *Psammocora (Stephanaria).* (Density of *A. ellisii:* $0.007/m^2$ or $1/138m^2$.)

Two stations were made at the northwestern extremity of Bahia de San Gabriel, located in the southwestern sector of Isla del Espiritu Santo. The first, Station 9, was located just outside and to the north of the bay at Punta Prieta and covered approximately $600m^2$ of rock ledges and boulders in water less than 5m deep. Coral coverage was between 3 and 4%, principally *Pocillopora,* and under ledges, *Tubastrea.* No *Acanthaster* were found during the day or night.

Station 10 was located just inside the bay where a fringing reef is forming in shallow water. Coral growth terminated on a sand bottom in less than 2.5m of water. Squires (1959) described a series of coral patches aligned as a barrier across the central portion of this same bay; however, that area was not investigated. Four species of *Pocillopora* were the principal reef builders with occasional scatterings of *Pavona, Psammocora (Stephanaria),* and *Porites.* At one end of the reef structure there was an extensive patch of *Porites* in very shallow water. Approximately 1500m^2 were thoroughly searched by snorkeling during the day. A single specimen of *A. ellisii,* the largest located during the survey, was found under a large head of *Pocillopora* that had a freshly killed portion comparable in size to the disk area of the starfish. No other *Acanthaster* were found at this station. However, occasional small white patches were noted on branch tips of *Pocillopora* clumps. Closer examination revealed that the regular five-armed sea star *Pharia pyramidata* (Gray) was everting its stomach in a manner similar to *Acanthaster* and removing coral tissue. Steinbeck and Ricketts (1941) reported *Pharia* to be common in coral areas in the Gulf of California, but our observation is the first to indicate that they feed on coral.

Thirty specimens of *A. ellisii* were collected. Disk diameters ranged from 62mm to 142mm with a mean of 97.9mm (Figure 2). No juveniles were found. All of these individuals fit within the size range of specimens available to Caso (1962), although our mean is slightly greater.

Gonad samples taken from 14 males and 12 females were analyzed by Dr. John S. Pearse of the Kerckhoff Marine Laboratory. Eighteen individuals were ripe, including the largest and smallest collected — both females. Numerous mature spermatozoa and a thick layer of spermatogenic cells in the 11 ripe males, and the presence of various-sized, growing oocytes alongside abundant, fully developed ones in the 7 ripe females, suggests that gametes are produced over a considerable period of time, or that the samples were taken during the peak of reproductivity. Four females contained several sizes of maturing oocytes but few full-grown ones. One female had recently spawned and appeared to be beginning a new cycle of gametogenesis. Three males were not ripe but were either maturing or perhaps had recently spawned and were beginning a new cycle of gametogenesis.

DISCUSSION

The behavior of *A. ellisii* differed from that described for *A. planci* by Goreau (1964) and Chesher (1969). Rather than hiding by day and feeding at night, *A. ellisii* was almost always conspicuously out in the open, and usually feeding, during the day. All *A. ellisii* but one were seen in water shallower than 4m. Their limited distribution was undoubtedly related to the narrow distributional limits of suitable food organisms. There was no apparent clumping of *Acanthaster* on a scale of a few tens of square meters.

Hermatypic scleractinian corals appeared to be the preferred food item for *A. ellisii* — particularly small encrusting patches of *Porites* estimated to be no more than 2 years old. Feeding experiments tended to support this observation. Goreau (1964) noted that in the southern Red Sea *A. planci* selected smaller coral heads more frequently than larger ones. There was no field evidence that *Acanthaster* feeds on the ahermatypic coral *Tubastrea,* and this coral was avoided in feeding experiments. However gorgonians of the genus *Pacifigorgia* were fed on occasionally, and one *Acanthaster* was seen in normal feeding attitude on a clump of the alga *Padina.*

All areas surveyed except the northwestern portion of Isla San Francisco were in the lee of the prevailing northwesterlies (November to May) and southeasterlies (June to October) (Roden, 1964). Such normally sheltered locations have been reported to support

larger average *Acanthaster* population levels (Chesher, 1970; Weber, 1970).

Ninety *Acanthaster* (including the 20 taken by Faulkner) were located within the 20,250m^2 surveyed in detail. The average density obtained, 0.0045/m^2 or about 1/225m^2, exceeds several of Chesher's definitions of normal population densities for *A. planci:* 2 or 3/1000m^2, 4 or 5/km of reef, 1/hour of search, and 20/20 minutes of search but usually no more than 8 (Chesher, 1969, 1970). For several stations densities approached, and at one station exceeded, the density reported for the infestation of Double Reef, Guam (886 animals on 90,000m^2 of reef, Chesher, 1969). The effect of the starfish on coral formations in the lower Gulf of California is certainly problematical, especially considering the general lack of reef development and sparse distribution of corals in that area (Squires, 1959). Excluding the 2 stations from Bahia de San Gabriel, coral coverage, in terms of projected images of individual colonies, averaged about 3% over 18,150m^2. There are then approximately 6.1m^2 of coral standing crop available for each *Acanthaster,* although the actual feeding surface is certainly greater. Using a consumption rate of twice the area of the disk per day (Chesher, 1969, for *A. planci*), approximately 5.3m^2 of coral would be consumed by an average size *A. ellisii* in a year's time. Such a feeding rate would require a replacement rate of coral standing crop — in terms of areal coverage — of 87% annually. However, this feeding rate, considering the effects of temperature differences on metabolic rate (Kinne, 1963), is probably an overestimate (surface temperatures in the lower Gulf of California range from 17 to 31°C with an annual mean of 24.7°C, while the tropical western Pacific remains nearly uniform at 28°C; see Roden, 1964).

The relationship between increase in weight and increase in area of the projected image of a coral colony is difficult to estimate and depends in a complex manner on such factors as growth form, degree and mode of branching, and skeletal density. Nevertheless, growth data giving annual increments of increase as per cent gain in weight does not seem an unreasonable means of approximating a coral replacement rate. In Hawaii, Edmondson (1929) found an average annual weight increase for a number of colonies of various sizes of two species of *Porites* to be 60.7% and 90.4% and of three species of *Pocillopora* to be 148.0%, 137.5%, and 103.9%. Since the Hawaiian Islands are on the border of the tropics, coral growth data from there seem appropriate for comparison, even though Hawaiian growth rates certainly exceed those in the lower Gulf of California. Despite the complications, it appears that under present conditions coral growth alone should be sufficient to provide enough tissue to satisfy the energetic requirements of current population levels of *A. ellisii.*

The gonad analysis indicates that in the Gulf of California *Acanthaster* has at least a protracted, if not continuous, spawning season. This does not agree with the report from Green Island (about 16°S) on the Great Barrier Reef of a highly synchronous breeding season in December and January for *A. planci* (Endean, 1969), nor with the contention of Chesher (1969) of a breeding season for *A. planci* at Guam (about 16°N) during November and December. Our data, however, agree with analyses by Pearse on specimens from Guadalcanal, Guam, Ifaluk, and Wolei (Eldredge, 1970), and with Mortensen's observation (1931) from off Java (about 6°S) that, for *A. planci,* the sexual products are not shed all at once but in portions at different times. Furthermore, continual influx of young, or recruitment extending over many months, could account for the lack of modes representing year classes in the size-frequency distribution of the populations of *A. ellisii* observed.

Since no growth rate data are available for *A. ellisii,* age structure of the populations cannot be inferred from their size distribution. However, one important point about the shape of the size-frequency curve, as it relates to population increases, should be made: the peak at intermediate sizes (see Figure 2) does not necessarily indicate an unusually large

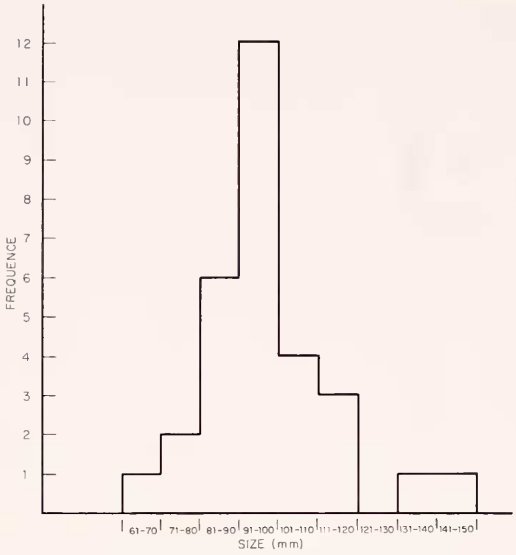

Figure 2. Size frequency histogram based on 30 specimens. Range, 62-142 mm; mean, 97.9 mm (median, 95.5 mm).

recent influx of young. Several combinations of survivorship curves coupled with non-linear growth could give size-frequency distribution curves of the shape observed even when annual recruitment is relatively constant over a period of several years. Probably the populations observed contain individuals in several year classes, and any contention for a recent population increase would be highly speculative.

Lacking adequate knowledge of recruitment, settling requirements, survivorship, spawning periods and behavior, growth rates, rates of mortality from various sources, and longevity of both corals and *Acanthaster,* as well as information concerning past population levels and fluctuations, we consider drawing any conclusions as to the consequences of present levels of predation on corals in the lower Gulf of California by *A. ellisii* tenuous at best. However, the feeding pressure exerted by *A. ellisii,* when coupled with suboptimal temperatures for corals resulting in relatively slow growth rates, an observed abundance of boring organisms, and paucity of coralline algae to serve as a binding agent, may contribute significantly to the almost total absence of reef formation in the Gulf of California.

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